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ORBITAL PAYLOAD POTENTIAL: SATURN IB EARTH LAUNCH VEHICLE USING SOLID PROPELLANT MOTORS

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by M. A. PAGE
Future Projects Office

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ORBITAL PAYLOAD POTENTIAL: SATURN IB EARTH LAUNCH VEHICLE USING SOLID PROPELLANT MOTORS

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ABSTRACT

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The purpose of this report is to summarize methods studied, or being studied, to increase the payload capability of the Saturn IB using solid propellant rocket motors. The background and status of large solid motor study programs funded by NASA and DOD are presented. The application of 305-cm (120-inch), 396-cm (156-inch), and 660-cm (260-inch) diameter solid motors are discussed. Some significant conclusions based on the studies are presented along with some recommendations for further investigation.

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TECHNICAL MEMORANDUM X-53083

ORBITAL PAYLOAD POTENTIAL: SATURN IB EARTH LAUNCH VEHICLE USING SOLID PROPELLANT MOTORS

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RESEARCH AND DEVELOPMENT OPERATIONS
FUTURE PROJECTS OFFICE

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TECHNICAL MEMORANDUM X-53083

ORBITAL PAYLOAD POTENTIAL: SATURN IB EARTH LAUNCH VEHICLE USING SOLID PROPELLANT MOTORS

SUMMARY

Summarized in this report are investigations to increase the payload capability of the Saturn IB using solid propellant rocket motors. Large solid motor development programs funded by NASA and DOD are discussed from a background and status standpoint. The application of large solid motors, i.e., 305-cm (120-in.), 396-cm (156-in.), and 660-cm (260-in.) diameter motors, are discussed.

The significant conclusion reached is that large solid propellant rocket motors can be used to efficiently increase the orbital payload capabilities of the Saturn IB. An increase in payload capability of approximately 170 percent can be realized with the proper combination of the Saturn IB and solid motors.

It is recommended that more detailed studies be initiated to explore the use of 350-cm and 660-cm diameter motors to increase the payload capability. These studies should include such factors as effects of loads, acoustics, vibrations, base heating, etc., on the complete vehicle.

SECTION I. INTRODUCTION

Two large launch vehicles are being developed by NASA for use in the manned lunar landing program. The Saturn V is being developed to propel the lunar landing and return craft into a 72-hour lunar transfer. The Saturn IB will play a lesser role in the Apollo program, which includes service as the test vehicle to prove feasibility of the Apollo capsule and landing vehicle. The Saturn IB also will be used to test the re-entry capabilities of the Earth return module.

The basic Saturn IB vehicle has the capability of placing approximately 1591 kg (35,000 lb) into a low Earth orbit. This will permit testing of the Apollo spacecraft without the full propellant capacity onboard. Furthermore, it is conceivable that space laboratories might weight more than the present Saturn IB can carry. Thus, the problem of increasing the payload capability is of immediate interest to NASA.

The payload capability of the Saturn IB may be increased by several methods. The liquid propellant engines could be uprated, higher performance propellants could be used, additional engines could be added, solid propellant motor augmentation could be utilized, or solid motors could be used to replace the liquid booster.

The purpose of this report is to summarize, in one document, the methods investigated, or being investigated, to increase the payload capability of the Saturn IB using solid propellant rocket motors. The report presents the background and status of large solid motor programs funded by NASA and DOD, and discusses the use of large solid motors to increase the payload capability of the Saturn IB.

SECTION II. SOLID MOTOR DEVELOPMENT PROGRAMS

A. GENERAL

Considerable effort and funds have been invested in solid motor research and development by NASA and DOD. Contracts with industry have been funded by NASA to investigate basic performance benefits and establish basic configurations using solid motors to increase the payload performance of the Saturn IB. In addition to the contracted investigations, NASA has conducted in-house exploratory activities in this area. Also, some of the solid motor and airframe manufacturers have performed company funded studies of the basic concepts involved.

The Air Force Titan III program is presently sponsoring the development of a 305-cm (120-in.) diameter segmented solid motor. The Air Force and NASA have jointly initiated a feasibility demonstration program for a 660-cm (260-in.) diameter, half-length (937 in.) motor, and a 396-cm (156-in.) diameter segmented motor to be used for component testing. Beginning in Fiscal Year 1965, NASA will probably fund the 660-cm motor demonstration program and the Air Force will continue the 305-cm and 396-cm motor investigations. The Air Force will probably continue to be overall manager of these programs.

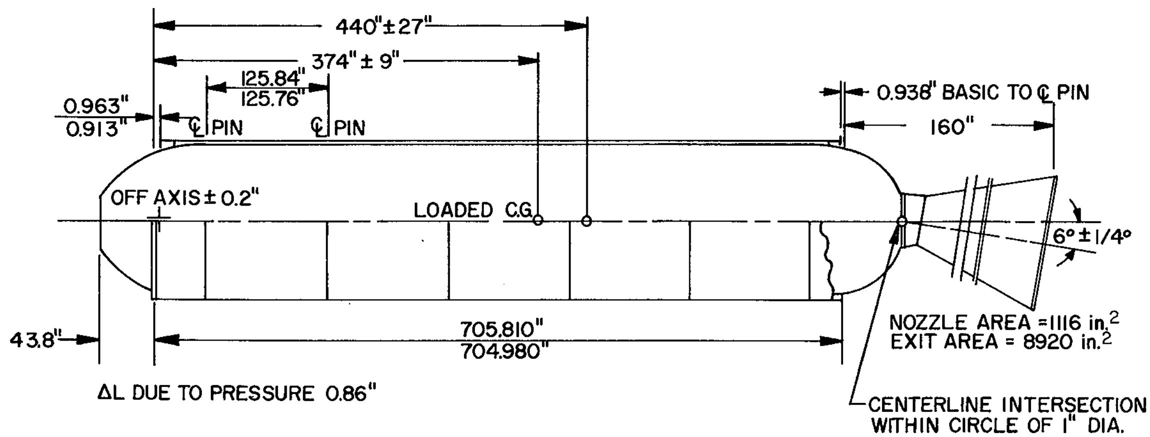
B. 305-cm (120-In.) MOTOR

Prior to the initiation of a development program for large solid motors, motor manufacturers designed, manufactured, and tested sub-scale motors of 254-cm (100-in.) diameter and less. Based on the results of these tests, the Air Force contracted with United Technology Corporation to develop and test a full-scale 305-cm diameter segmented motor for the Titan III (624 A) system. As of September 1964, four, five segment, 350 cm motors had been fired; two were successful, the third failed due to a burn-through in the motor case, and the fourth experienced a nozzle failure in the last few seconds of the test.

TABLE I. CONTEMPLATED PERFORMANCE PARAMETERS: 120-INCH DIAMETER SOLID MOTOR [Ref. 2]

Parameter	624A Motor (Titan III)	624A Modified Motor (SAT IB)
Web Action Time, sec	105.0	121.0
Erosion Rates, mils/sec	3.5	3.5
Average Chamber Pressure, psia	536.0	536.0
Nozzle Throat Diameter, in.	37.7	35.2
Expansion Ratio	8.0	8.0
Average Thrust, lb	852,500	751,900
Burning Rate at $\bar{P}_c$, in/sec	0.33	0.29
Total Impulse, lb-sec	92.31×10^6	92.31×10^6
Delivered Specific Impulse (Sea Level), sec	242.3	242.3

Table I presents the contemplated performance parameters for the Titan III motor (624 A) and the solid boosted Saturn IB vehicle motor (Modified 624 A). The configuration and weights of the Titan III motor (624 A) are shown in Figure 1. No significant changes will be required in the configuration and weights for the modified 624 A motor.



ITEM	MOTOR WEIGHTS (lb.)	
	5 SEGMENTS	4 SEGMENTS
PROPELLANT	412,000	339,600
HARDWARE AND INERT MATERIAL	52,520	47,115
TOTAL	464,520	386,715
MASS FRACTION	0.887	0.878

FIGURE 1. CONFIGURATION AND WEIGHTS FOR THE TITAN III (624 A) MOTOR [Ref. 1]

C. 396 cm AND 660 cm (156 AND 260-In.) MOTORS

The Air Force large motor feasibility demonstration program (623 A) was divided into four bid packages. Each of these packages outlined tasks to be completed and a scheduled firing date. The program is summarized in Table II. Figures 2 and 3 present the performance characteristics and weights of the 396-cm diameter motor used for gimbaled nozzle and jet tab tests, and the 396-cm diameter motor for the 660-cm motor nozzle development tests.

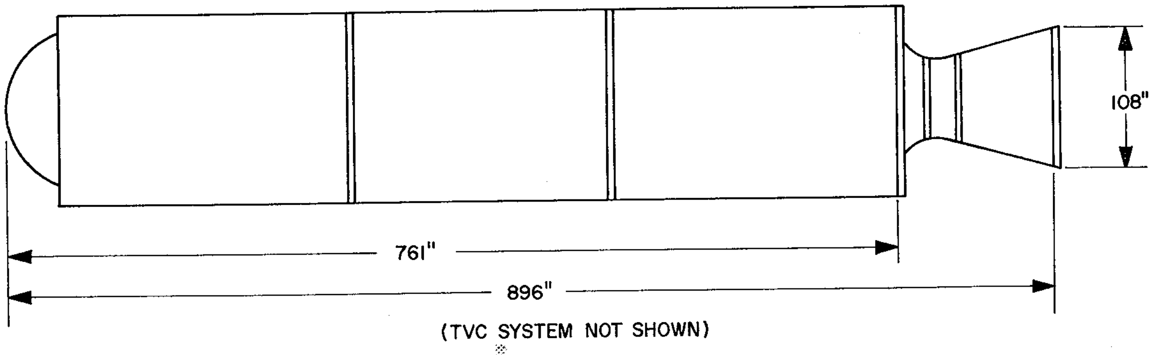
The performance and weights of the 396-cm motor will vary with the number of segments used to make up the motor. Table III presents performance data, dimensions, and weights for different numbers of center segments. Performance characteristics and weights of the 660-cm "half-length" motor, and a typical full length motor are shown in Figures 4 and 5, respectively.

The configurations presented are, in most cases, conceptual designs and are not to be construed as firm. Further analysis and investigation will be required prior to establishing firm configurations and performance requirements. Problems such as base heating, vibration, and launch requirements must be studied in much more depth before a firm configuration can be established.

TABLE II. AIR FORCE 623 A LARGE MOTOR DEMONSTRATION PROGRAM [Ref. 4]

BID PACKAGE	CONTRACTOR	TYPE MOTOR	TVC*	FIRING DATE
1	Thiokol	Half-Length 260" Dia.	-	Dec. 1964
		Half-Length 260" Dia.	-	June 1964
	Aerojet	Half-Length 260" Dia.	-	Jan. 1965
		Half-Length 260" Dia.	-	June 1965
2	Thiokol	156" Dia. (260" motor Nozzle Development Test)	-	August 1964
3	Thiokol	156" Dia. (Single Center Segment)	Gimbaled Nozzle	Nov. 1964
4	Lockheed	156" Dia. (Single Center Segment)	Jet Tab	May 1964
		156" Dia. (Single Center Segment)	Jet Tab	August 1964

* Thrust vector control



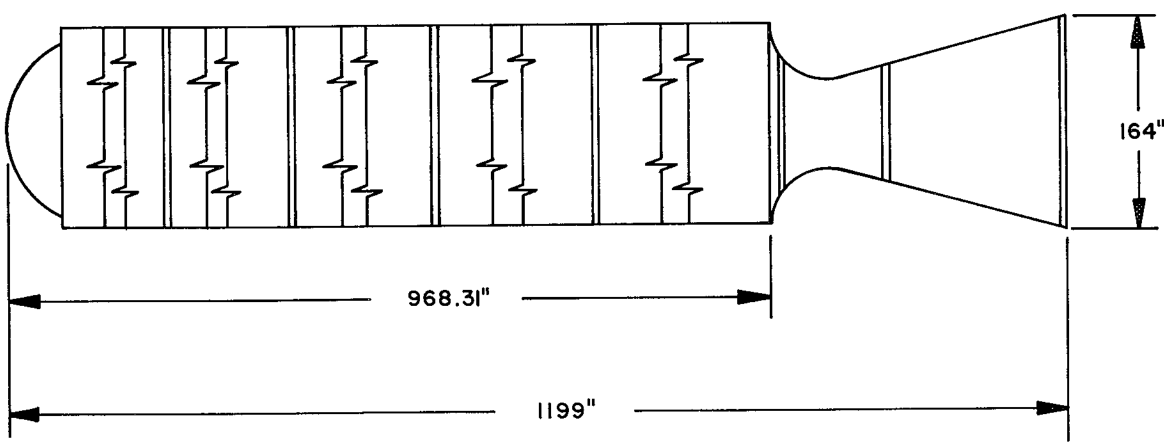
PERFORMANCE

NUMBER CENTER SEGMENTS – 1
THRUST – 1.343 x 10^6 lb.
WEB BURNING TIME – 120 sec.
TOTAL IMPULSE – 394 x 10^6 lb.-sec.
I_{sp}, S. L. – 238.3 lb.-sec./lb.

WEIGHTS (lb.)

CASE, HI-NICKEL STEEL	56,380
NOZZLE, CARBON CLOTH ERODABLE PLASTICS	9,808
PROPELLANT	697,400
LINER AND INSULATION	8,295
TOTAL	771,950
MOTOR MASS FRACTION	.898

FIGURE 2. 156" MOTOR FOR GIMBAL NOZZLE AND JET TAB TESTS [Ref. 4]



PERFORMANCE

NUMBER CENTER SEGMENTS - 3
THRUST - 3.42 × 10^6 LB
WEB BURNING TIME - 51.3 SEC
TOTAL IMPULSE - 189 × 10^6 LB-SEC
I_{SP}, S.L. - 236 LB-SEC/LB

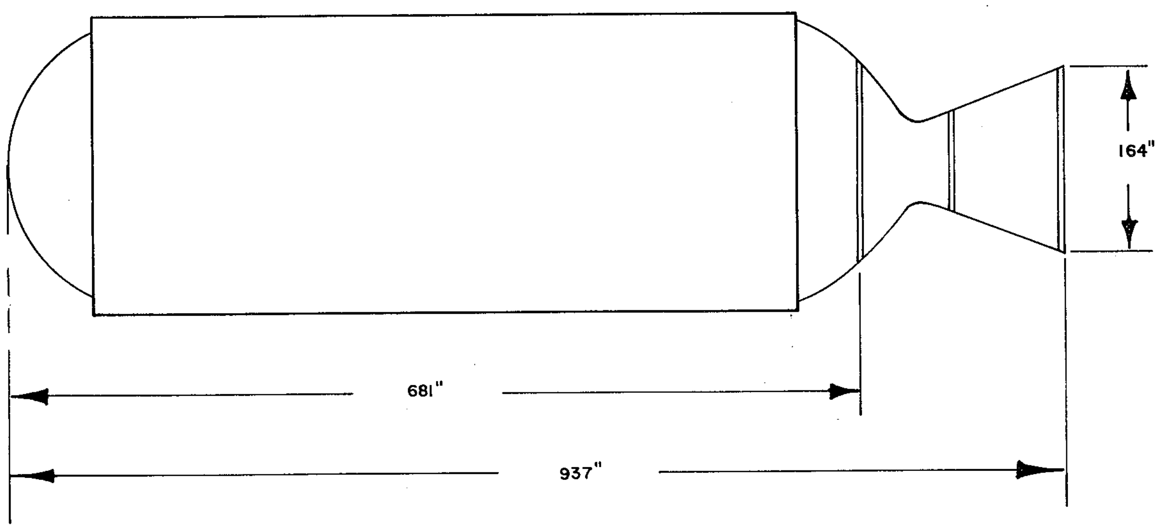
WEIGHTS (LBS)

CASE HI-NICKEL STEEL	- 70,900
NOZZLE-CARBON CLOTH ERODABLE PLASTICS	- 21,100
PROPELLANT	- 808,700
LINER AND INSULATION	- 8,600
TOTAL	- 909,300
MOTOR MASS FRACTION	- 0.89

FIGURE 3. 156" MOTOR FOR 260" NOZZLE DEVELOPMENT [Ref. 4]

TABLE III. 156" MOTOR DATA FOR DIFFERENT NUMBER OF CENTER SEGMENTS [Ref. 4]

	0 CENTER SEGMENT	1 CENTER SEGMENT	2 CENTER SEGMENTS	5 CENTER SEGMENTS
PERFORMANCE				
Thrust (lb)	$.536 \times 10^6$	1.343×10^6	2.4813×10^6	3.281
Web Burning Time (sec)	91.75	120	89.50	120
Total Impulse (lb-sec)	49.3×10^6	161×10^6	229×10^6	394×10^6
Specific Impulse, S.L. (lb-sec-lb)	216.6	238.3	242.2	241.8
DIMENSIONS (IN.)				
Total Length	431	896	1,260	2,032
Case Length	314	761	1,048	1,804
Nozzle Length	117	135	212	228
Nozzle Exit Diameter	120	108	155	167
WEIGHTS (LB)				
Case	23,095	56,380	73,761	133,272
Nozzle	11,373	9,808	12,516	26,839
Liner and Insulation	3,558	8,295	11,220	16,659
Propellant	241,700	697,400	945,900	1,714,290
Total Weight	279,726	771,950	1,043,396	1,890,770
Motor Mass Fraction	.864	.898	.906	.900



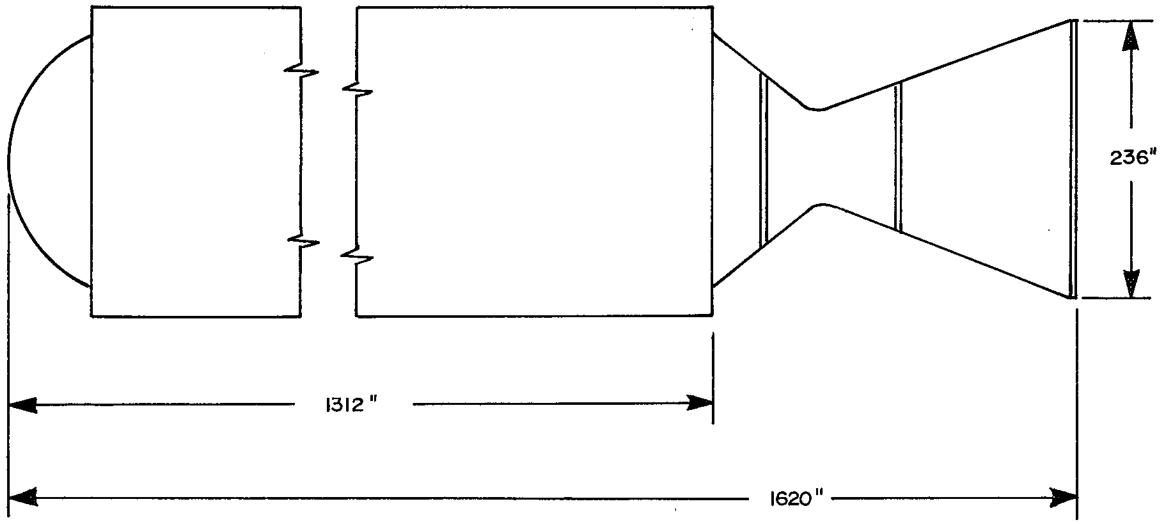
PERFORMANCE

THRUST - 3.28×10^6 LB
WEB BURNING TIME - 110 SEC
TOTAL IMPULSE - $.378 \times 10^6$ LB-SEC
I_{SP}, S.L. - 235 LB-SEC/LB

WEIGHTS (LBS)

CASE, HIGH NICKEL STEEL	- 125,000
NOZZLE, CARBON CLOTH ERODABLE PLASTIC	- 27,000
PROPELLANT	- 1.618×10^6
LINER AND INSULATION	- 15,000
TOTAL	- 1,785,000
MOTOR MASS FRACTION	- 0.90

FIGURE 4. HALF LENGTH 260" MOTOR [Ref. 4]



PERFORMANCE

THRUST – 6.50×10^6 lb.
WEB BURNING TIME – 110 sec
TOTAL IMPULSE – 760×10^6 lb – sec
I_{sp}, S.L. – 232 lb – sec/lb

WEIGHTS (lb.)

CASE, HIGH NICKEL STEEL – 216,000
NOZZLE, CARBON CLOTH – 50,000
ERODABLE PLASTICS
PROPELLANT – 3.297×10^6
LINER AND INSULATION – 18,000
3,571,000
MOTOR MASS FRACTION – .92

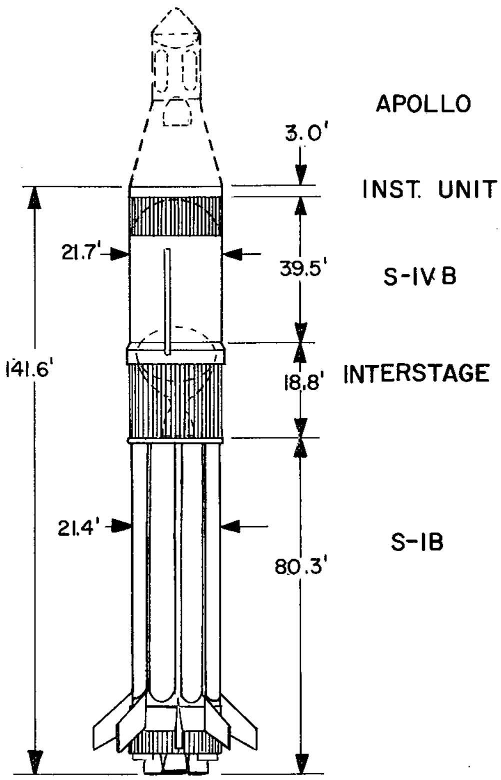
FIGURE 5. TYPICAL 260" FULL LENGTH MOTOR [Ref. 4]

SECTION III. SOLID MOTOR APPLICATIONS: SATURN IB

A. SATURN IB OPERATIONAL CONFIGURATION

The operational Saturn IB vehicle will consist of S-IB and S-IVB stages, instrument unit, and payload. The payload of the operational vehicle will be approximately 1591 kg (35,000 lb) to a 185-km orbit.

The first stage (S-IB) propulsion system is made up of eight H-1 engines, which develop 890 kN (200,000 lb) of thrust each at sea level conditions. The second stage (S-IVB) has one J-2 engine which develops a thrust of 89 kN (20,000 lb) at vacuum conditions. The operational configuration and performance data are shown in Figure 6.



	FIRST STAGE	SEC. STAGE
ENGINE TYPE	H-I (8)	J-2 (1)
PROPELLANTS	LOX/RP I	LOX/H_2
THRUST/ENGINE, LB	200,000 (SL)	200,000 (VAC)
SPECIFIC IMPULSE, SEC	258 (SL)	426 (VAC)
STAGE AT LIFT OFF, LB	987,750	252,450
USEABLE PROPELLANT, LB	880,450	230,000
STAGE AT SEPARATION, LB	107,300	22,450
INTERSTAGE, LB	5600	
INSTRUMENTATION UNIT, LB	2560	

FIGURE 6. OPERATIONAL SATURN IB CONFIGURATION-1966 PERIOD [Ref. 5]

Operational cost of the Saturn IB is estimated to be $1210 per kg ($550 per pound) [Ref. 3] of payload placed in a 185-km orbit. A reliability of 0.905 and 139 launches are assumed.

B. SOLID MOTOR FIRST STAGE

1. General. The use of large solid propellant motors to replace the S-IB stage of the Saturn IB has been investigated. Consideration has been given to the use of clustered 305-cm diameter motors and 660-cm diameter "half-length" and "three-fourth-length" motors. The application of each of these is discussed in the following paragraphs.

2. Clustered 305-cm (120-In.) Motor [Ref. 1]. Clusters of the 305-cm diameter motor as a replacement for the S-IB stage were investigated.

The clusters considered consisted of three, four, and five motors with four and five segments making up the motors in each cluster. Typical clusters consisted of:

a. Three motors, triangular;

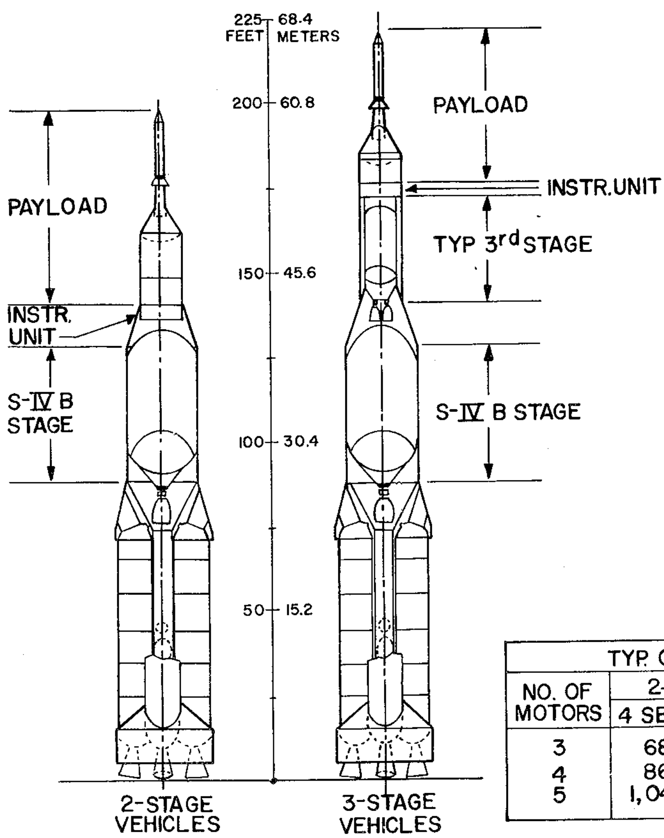
b. Four motors, periphery;

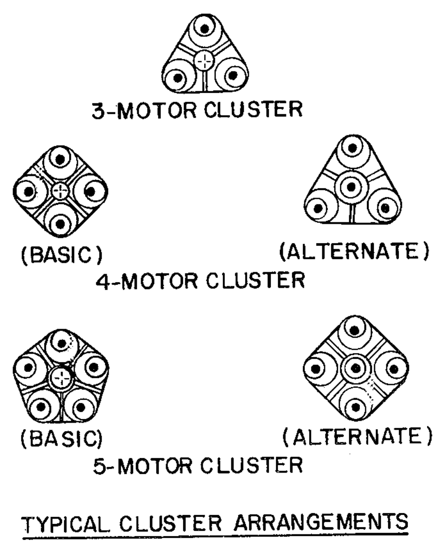
c. Four motors, three peripherally around the fourth;

d. Five motors, periphery;

e. Five motors, four peripherally around the fifth.

Motor cluster arrangements and basic vehicle configurations for both two-stage and three-stage vehicles are shown in Figure 7.





TYP. GROSS WTS.-KG (BASIC CLUSTERS ONLY)				
NO. OF MOTORS	2-STAGE VEHICLES		3-STAGE VEHICLES	
	4 SEGMENT	5 SEGMENT	4 SEGMENT	5 SEGMENT
3	685,275	793,888	688,916	797,575
4	865,990	1,010,823	869,654	1,014,532
5	1,046,795	1,227,802	1,050,482	1,231,534

FIGURE 7. BASIC CONFIGURATIONS [Ref. 1]

The cluster of five 305-cm diameter segmented solid-propellant motors as the first stage, with the S-IVB as the second stage, was selected as the basic configuration. This vehicle is capable of delivering a gross weight of approximately 24,970 kg (55,000 lb) into a 185-km orbit.

TABLE IV. CLUSTERED 120-INCH MOTOR PERFORMANCE SUMMARY [Ref. 1]

MOTORS CLUSTERED	185-KM ORBITAL PAYLOAD (KG)	
	4 Segment Motor	5 Segment Motor
3	13,800	18,400
4	19,200	22,600
5	22,300	25,800

NOTES

1. Performance summary is for a saddle shaped thrust profile.

2. Performance is based on optimized trajectories which satisfied maximum.

Table IV summarizes the payload capability of the vehicles considered. All combinations of motors and segments satisfy the dynamic-pressure limitation of 950 psf, and utilize the maximum S-IVB propellant loading, optimum for all cases. The payloads reflected in Table IV are based on the assumptions and weights presented in Table V.

The analysis shows that the clustering of five 305-cm solid propellant motors can be done with a minimum of additional structure. The first stage solid motors require no additional strengthening and the margins of safety are quite high (approximately 1.4). The S-IVB stage was found to be conditionally adequate. Differences between the Saturn V and Saturn IB loads, arising out of elastic versus rigid vehicle considerations, had not been resolved by NASA at the time of the study.

TABLE V. CLUSTERED 120-INCH MOTOR ANALYSIS: ASSUMPTIONS AND STAGE WEIGHTS [Ref. 1]

ASSUMPTIONS

Two stages to 185-km circular orbit

Gravity turn in first stage, except for initial pitch program

Optimized second-stage thrust vector attitude program

S-IVB thrust level = 90, 800 kg

Allowable maximum dynamic pressure = 4, 638 kg/m^2

Allowable maximum load factor = 8 g

FIRST STAGE WEIGHT SUMMARY (KG)

Cluster	Number of Segments per Motor			
	4 Propellant*	Inert**	5 Propellant*	Inert**
3 Motors	455, 589	78, 499	554, 334	87, 306
4 Motors	607, 452	102, 288	739, 112	114, 047
5 Motors	759, 315	126, 169	923, 797	140, 833

* Total propellant consumed, including thrust vector control

** Total weight dropped at first staging

The estimated cost of the research and development phase, six launches, with solid motors priced at $6. 60 per kg ($3 per pound) totals $334 million. The development phase made no allowance for the solid motor in the 624 A program, but assumed complete cost chargeable to the program. The total required operational program funding is estimated to be approximately $1477 million for 69 flights over a period of 12 years.

The program contemplated the modification and use of Launch Complex 34 for the six planned R&D flights. Based on 69 operational launch attempts and a 100 percent successfully delivered (23,900 kg) payload, an average operation cost of approximately 900$/kg (408$/lb) with an average total cost of approximately 1100$/kg (495$/lb) have been estimated. Costs were based upon $6.60 per kg (3$/lb) for solid motors and the cost of the S-IVB stage, instrument unit, interstage, etc., based on calendar year 1963 estimates.

3. Single 660-cm (260-In.) Motor. A single 660-cm diameter solid motor was considered as a replacement for the S-IB stage. Several organizations conducted preliminary studies of the use of this motor for this particular application. The Boeing Company, Seattle, Washington, included this application in a parametric study conducted under a contract with MSFC [Ref. 3]. They investigated a point design of a "half-length," 660-cm diameter solid motor for a booster, and the S-IVB as a second stage. Also, parametric data were generated for vehicles using 660-cm diameter motors greater than one-half length, with payload capabilities ranging from 2432 kg (53,500 lb) to 3545 kg (78,000 lb) into a 185-km orbit. Figure 8 presents a curve of the payload weight to a 185-km orbit versus booster solid propellant weight. Also shown in Figure 8 is the relationship of launch weight to payload ratio versus the booster solid propellant weight.

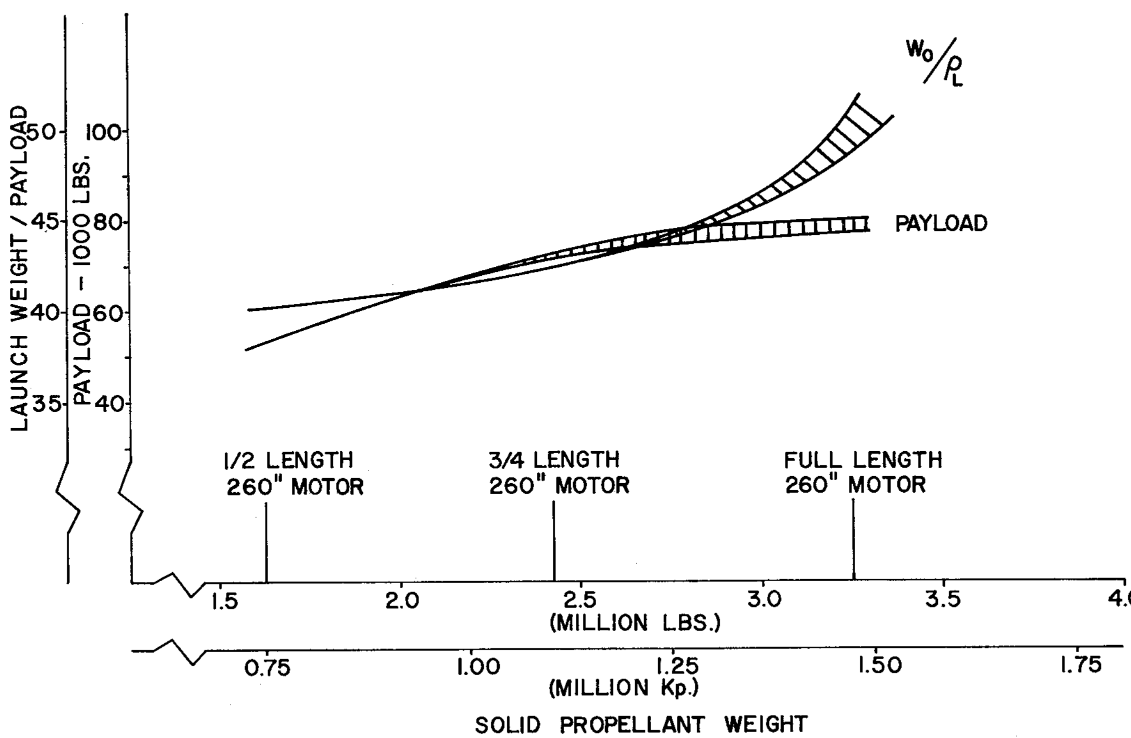


FIGURE 8. FIRST STAGE SIZE EFFECTS - SOLID BOOSTED S-IVB [Ref. 3]

Several industrial and MSFC in-house organizations have conducted preliminary surveys to determine the approximate payload capability for a vehicle consisting of a S-IVB stage as defined for the baseline Saturn IB vehicle, with necessary modifications, and a 660-cm diameter solid propellant booster. Table VI presents the payload estimates made by these organizations.

TABLE VI. PRELIMINARY 260-INCH DIAMETER SOLID MOTOR BOOSTED VEHICLE DESIGN

SOURCE	FIRST STAGE PROPELLANT WEIGHT (LB)	PAYLOAD (LB)	RATIO LAUNCH WT./PAYLOAD WT.	OPERATIONAL COST/LB ORBIT ($)
Boeing	1.62×10^6	53,500	39.4	299 (80 vehicles) (a)
Boeing	2.43×10^6	71,000	42.0	257
Boeing	2.70×10^6	75,000	43.5	253
Boeing	3.24×10^6	78,000	49.5	262
Aerojet	1.665×10^6	49,900	43.9	-
Aerojet	1.972×10^6 (b)	61,200	41.1	-
Aerojet	2.500×10^6 (c)	69,900	44.7	-
MSFC, P&VE	1.58×10^6	45,400	-	-
MSFC, P&VE	1.67×10^6	52,900	-	-
MSFC, P&VE	2.40×10^6	65,395	45.7	-
MSFC, P&VE	2.40×10^6 (d)	89,580	35.0	-
Boeing	Basic Saturn-IB	32,400	39.8	550 (139 vehicles)

(a) $395/lb in orbit for 10 launch vehicles

(b) Optimum loaded 1/2 length first stage

(c) Optimum length first stage

(d) Improved S-IVB stage

The effects of the solid propellant motor and increased payload weight on the structure of the S-IVB stage remain to be determined in detail. However, preliminary investigation indicates that the loads obtained using the solid first stage exceeded those for which the existing S-IVB was designed. The only major modification probably will be changing the aft interstage to withstand the increased loads, and to accommodate the 660-cm solid motor. Modifications to the S-IVB second stage because of the "half-length" solid motor replacement of the first stage would result in a 33 percent increase in second stage dry weight. Since vehicle payload in a 185-km orbit is increased by 37 percent, or more, the increase in second stage weight becomes insignificant in comparison.

Again, based upon the "half-length" solid motor booster for the S-IVB (2432 kg payload), an estimated launch thrust-to-weight ratio required to prevent the maximum dynamic pressure from exceeding 950 psf, a ratio of 1.33

was chosen. A trajectory time history, presented in Figure 9, shows that maximum dynamic pressure reached 880 psf, with a maximum tangential load factor of 6.3 g.

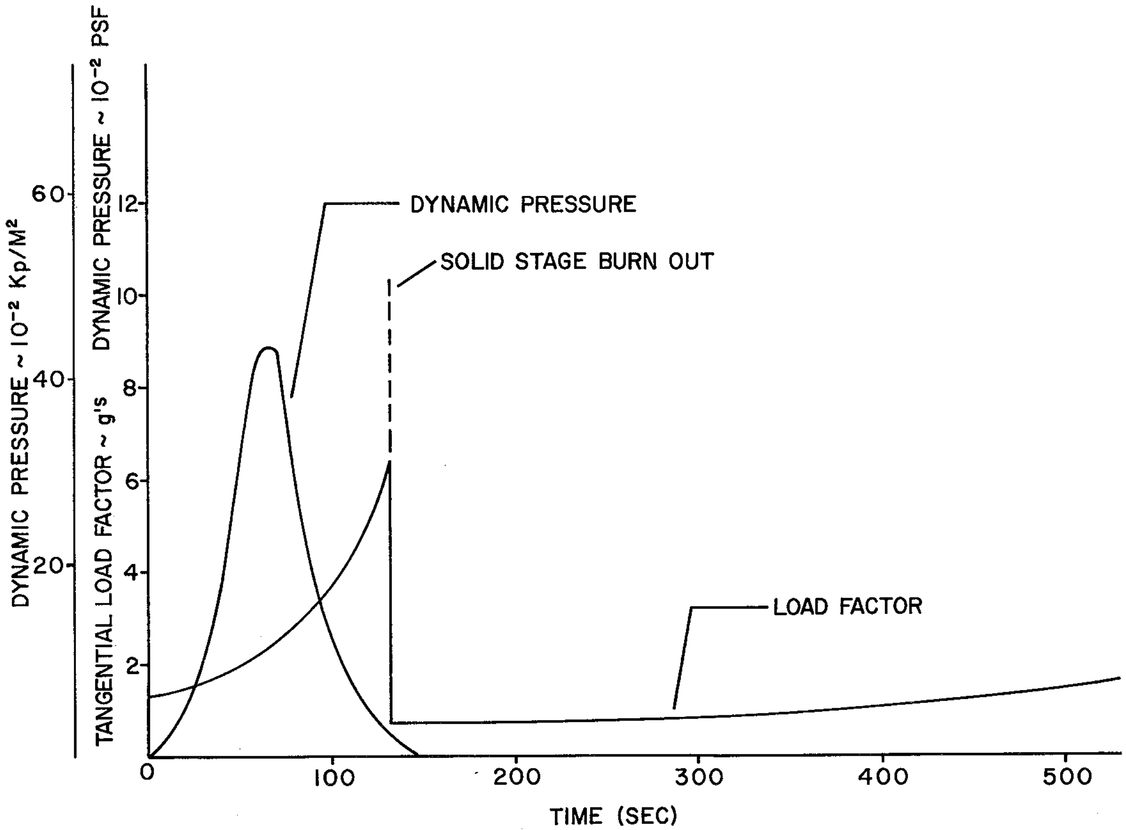


FIGURE 9. TRAJECTORY DATA - BOOSTED S-IVB STAGE [Ref. 3]

Estimated total costs for a launch vehicle using the "half-length" 660-cm diameter motor with .74 million kg (1.62 million lb) of propellant and the S-IVB stage are based on the following assumptions:

a. Six-vehicle flight-test program;

b. Two-year flight-test program;

c. Modifications of the S-IV stage only, no development cost;

d. Payload cost excluded;

e. Major portion of baseline Saturn IB instrument unit package could be used;

f. Cost based on 10 and 80 vehicles over a period of 3 and 10 years, respectively;

g. Existing facilities would be used or modified;

h. Previous and parallel flights of the baseline Saturn IB and V vehicles would accumulate reliability on the J-2 engine and S-IVB stage;

i. Complete development of the 660-cm motor charged to the program, no allowance made for the 623 A program.

Total estimated development program cost for the solid boosted S-IVB stage will be approximately \$550 million and \$123 million for facilities. Total operational cost based on 10 launches over a period of 3 years and 80 launches over a period of 10 years is estimated to be approximately \$180 million and \$1200 million, respectively. These costs result in a total cost effectiveness of \$4070 per kg (\$1850 per lb) and \$1023 per kg (\$465 per lb) of payload in 185-km orbit for the 10 launches and 80 launches, respectively.

The solid-boosted S-IVB vehicles may be launched from either Complex 34 or 37 (costing was based on Complex 34). Modifications will be required because of the increased vehicle weight, large volume of exhaust gases, and composition of exhaust gases as compared to the Saturn IB. These modifications will include:

a. Remove present launch pedestal and foundation, and construct two new pedestals;

b. Remove old and construct two new umbilical towers, equipment terminal rooms, and supporting foundations;

c. Construct new service tower to serve both launch positions;

d. Motor erecting crane.

Other equipments and facilities such as blockhouse, instrumentation, propellant and high pressure gas facilities, camera stations, etc., will be retained.

No conclusions can be reached concerning launch site suitability without further, more complete hazard evaluations. However, hazards appear sufficiently great to warrant consideration of new launch facilities.

An area of approximately 2225 m (7300 ft) radius must be cleared of personnel during final fueling and launch operations in order to maintain a 0.4 psi maximum blast overpressure limit for unprotected personnel. Figures 10 and 11 present curves of blast overpressures for launch vehicles on Complex 34 and 37, respectively.

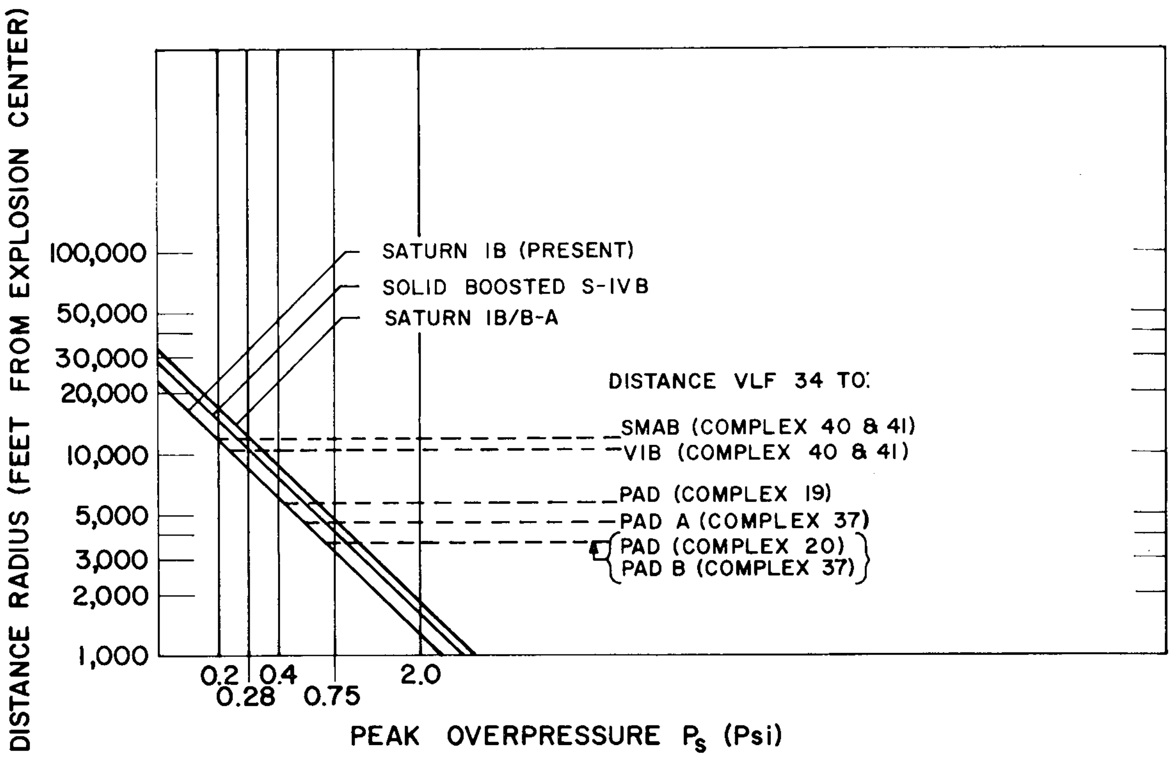


FIGURE 10. BLAST OVERPRESSURES - LAUNCH VEHICLES ON COMPLEX 34 [Ref. 3]

C. STRAP-ON SOLID MOTORS

The use of large solid propellant motors as auxiliary propulsion systems to increase the payload capacity of the baseline Saturn IB stage has been investigated. This method includes mounting the solid motors on the side of the S-IB stage and firing them simultaneously with the H-1 engines of the first stage.

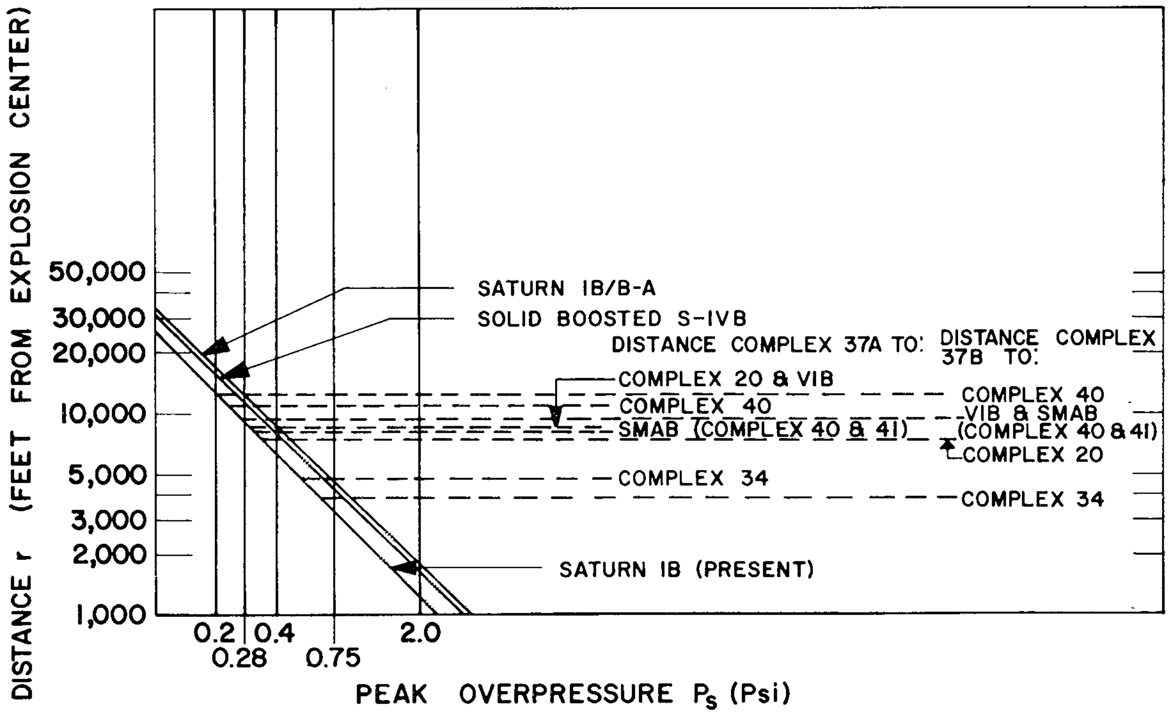
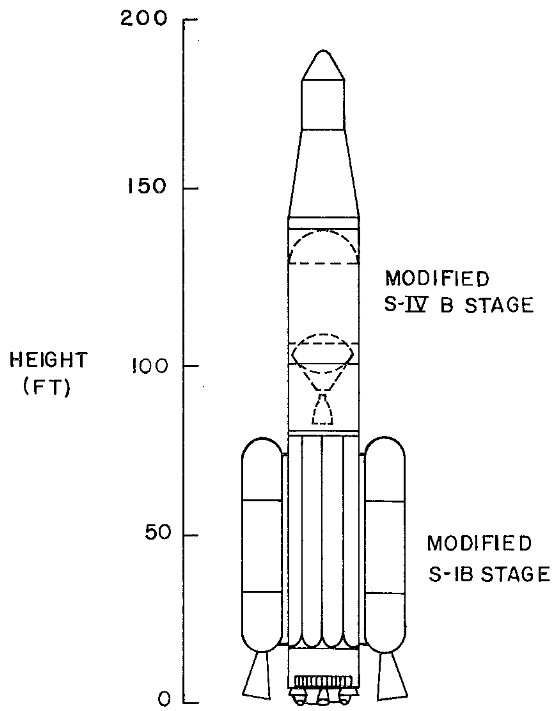


FIGURE 11. BLAST OVERPRESSURES - LAUNCH VEHICLES ON COMPLEX 37 [Ref. 3]

The burned out motor cases are staged prior to burn-out of the S-IB stage, or are retained until first and second stage separation, depending upon differential of burning time between the two systems. Consideration has been given to the use of 396-cm diameter and 305-cm diameter solid motors for this application. The following paragraphs discuss these applications.

2. 396-cm (156-In.) Strap-On [Ref. 3]. Two 396-cm solid motors, each with one center segment and having a total propellant weight of 634,000 kg (1,394,800 lb), were selected for consideration. The use of these motors provided a solid to S-IB propellant weight ratio of 1.58. Also, the overall length of 23.84 m (78.2 ft) makes them compatible with the S-IB stage (24.4 m) for structural attachment.



PAYLOAD	74,820 LB (33,850 KP)
LAUNCH WT	2,856,000 LB
LAUNCH THRUST	3,989,000 LB
BOOST-ASSIST PROPELLANT	1,395,000 LB
SOLID BURNTIME	131.9 SEC
QMAX	990 PSF

TWO-156 IN DIA. SOLID MOTORS

FIGURE 12. SATURN IB WITH BOOST-ASSIST (DIRECT ASCENT - 185 km) [Ref. 3]

The vehicle configuration selected for consideration is shown in Figure 12, and a summary of vehicle characteristics is presented in Table VII. Based on flight control studies of the Saturn IB with boost-assist, the vehicle will require some solid motor thrust vector control in addition to canted nozzles. Of course, the requirements for thrust vector control cannot be determined until a detailed investigation has been conducted.

The burning time for the 396-cm diameter motor considered for boost-assist application in this study is approximately 132 seconds. Since the engine operating time of the S-IB stage is approximately 148 seconds, the boost-assist

TABLE VII. SATURN IB WITH BOOST-ASSIST - SATURN IB CHARACTERISTICS (TWO 156-INCH MOTORS) [Ref. 3]

	SATURN IB WITH BOOST-ASSIST	BASIC/ SATURN IB
Payload to 185-km Orbit (lb)	74, 820	32, 400
Launch Weight (lb)	2, 856, 450	1, 290, 000
Launch Thrust to Weight Ratio	1.4	1.16
Launch Thrust (lb)	3, 989, 100	1, 500, 000
Boost-Assist Propellant Weight (lb)	1, 394, 800	-
Maximum Dynamic Pressure (psf)	990	548
Load Factor at First Stage Burnout (g's)	6.5	4.03
Reliability	.860	.905
Solid Motor Burn-time (sec)	131.9	-

motor could be retained until S-IB stage separation. Figure 13 shows preliminary dynamic pressure and load factor versus time.

Addition of the solid motors to the Saturn IB vehicle will impose increased loads on the S-IB and S-IVB stages. Attachments for mounting the solid motors, structural for thrust take-out, etc., will increase the dry weight of the S-IB stage by approximately 12 percent, whereas structural modifications of the S-IVB stage will account for approximately 5 percent dry weight increase.

Estimated total costs for a Saturn IB launch vehicle with two 396-cm (one segmented) solid boost-assist motors are based on the following assumptions:

a. Six vehicles will be launched in the development program;

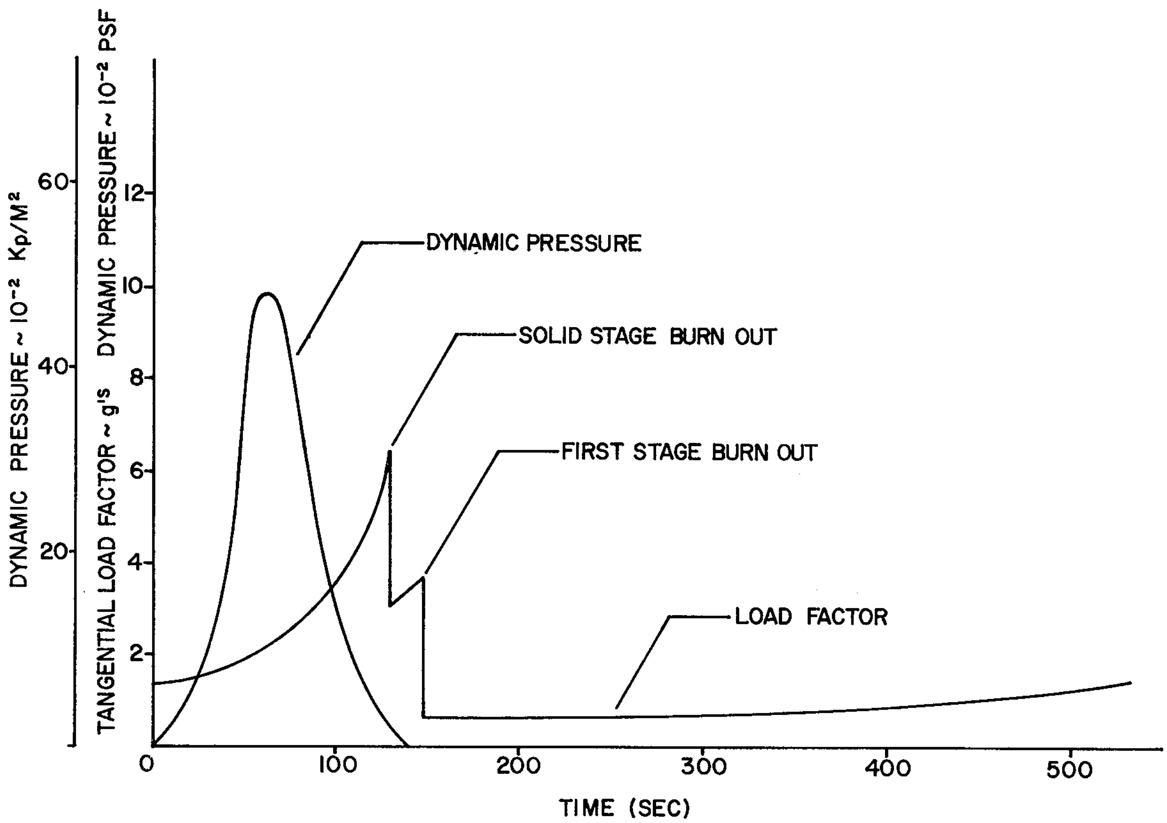


FIGURE 13. TRAJECTORY DATA - SATURN IB WITH BOOST-ASSIST [Ref. 3]

b. A two-year flight test program;

c. Saturn IB vehicle completely developed and paid for (cost connected with modifications of the S-IB and S-IVB stages are included);

d. Payload cost excluded;

e. Major portion of the instrument unit package of the existing Saturn IB was utilized;

f. Cost based on operational programs of 10 to 80 vehicles for a period of 3 and 10 years, respectively.

The boost-assist vehicle has an operational cost effectiveness of approximately \$825 per kg (375\$/lb) and a total cost effectiveness of \$1194 per kg (543\$/lb) in a 185-km orbit. These costs were based upon 80 launches over a 10-year period.

Launch site selection for the boost-assist Saturn IB will require consideration of vehicle operational hazards and range safety considerations. New launch pedestals will probably be required in addition to extensive modifications of environmental enclosures and access platforms. A facilities study will be required before modification and/or new facilities can be determined.

3. 305-cm (120-In.) Strap-On [Ref. 6]. Two 305-cm diameter solid motors, each with 187,273 kg (412,000 lb) of propellant, were considered for application as boost-assist for the Saturn IB launch vehicle. The method of attachments, mounting, etc., is very similar to the 396-cm strap-on. A sketch of the vehicle is shown in Figure 14, and the vehicle characteristics are presented in Tables VIII and IX. The performance of the vehicle with an improved S-IVB is given in Tables X and XI.

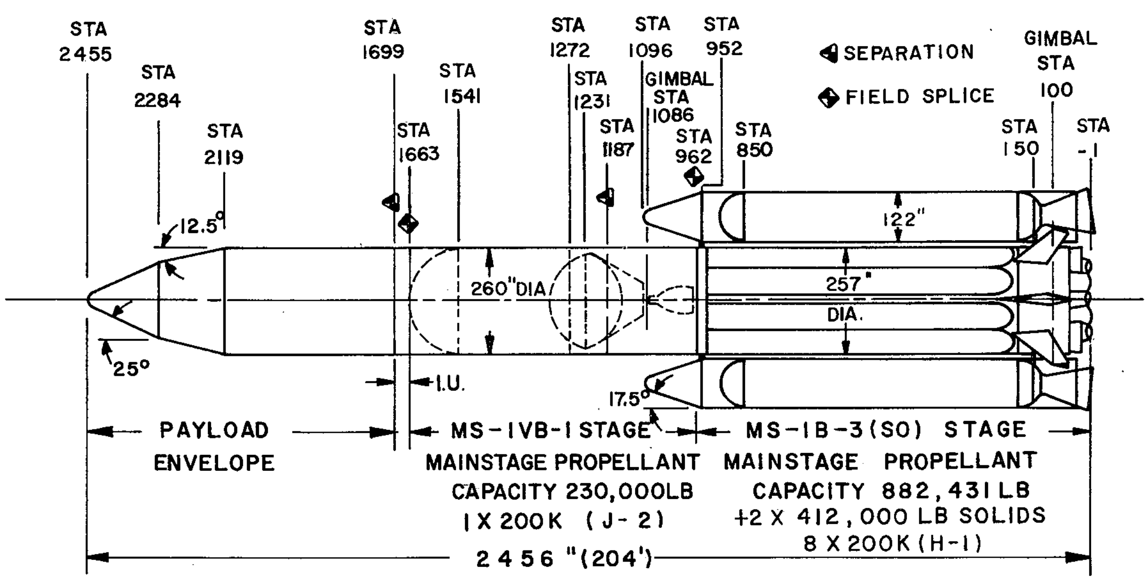


FIGURE 14. BOOST-ASSIST SATURN IB EARTH LAUNCH VEHICLE [Ref. 6]

TABLE VIII. FIRST STAGE WEIGHT SUMMARY: S-IB WITH 120-INCH SOLID STRAP-ON AND S-IVB (MLV-SAT-IB-7-SO) [Ref. 6]

(8 x 200K lb. Thrust, Isp = 258.8 sec, S.L.)
(2 x 1,000K lb Thrust, Isp = 224 sec, S.L.)

		LIFT-OFF WEIGHT (LB)	SEPARATION WEIGHT (LB)
Second Stage Lift-off		317,461	317,461
MS-IB-3 (SO)/MS-IVB-1 Interstage		7,350	7,350
MS-IB-3 (SO)/MS-IVB-1 Sep/Start Loss		693	693
MS-IB-3 (SO) Stage (Dry)		98,200	98,200
Mainstage Propellant (LOX/RP-1)		882,431	-
Residuals		11,050	11,050
Pressurization Gas (Fuel)	44		
Helium Trapped	36		
Fuel Bias	1,900		
Pressurization Gas (Oxidizer)	3,279		
Nitrogen Trapped	14		
Hydraulic Oil	28		
Fuel Trapped	2,957		
Oxidizer Trapped	2,792		
Thrust Decay		4,301*	241
Liquid Service Items		1,579	-
Solid Motor Propellant		824,000	-
Solid Motor Liners, Nozzles, Chambers, etc.		106,040	106,040
		2,253,105	541,035

$(T/W)_{LO} = 1.593$

* Includes 2,177 lb for inboard engines thrust decay and 1,883 lb for outboard engines thrust decay to .8 sec outboard engine cutoff

TABLE IX. SECOND STAGE WEIGHT SUMMARY: S-IB WITH 120-INCH SOLID STRAP-ON AND S-IVB (MLV-SAT-IB-7-SO) [Ref. 6]

(1 x 200K lb thrust, I_{sp} = 426 sec, vac)

		LIFT-OFF WEIGHT (LB)	CUTOFF WEIGHT (LB)
Gross Payload		52,397	52,397
Instrument Unit		4,059	4,059
MS-IVB-1 Stage (Dry)		29,043*	28,800
Mainstage Propellant (LOX/LH_2)		228,290	-
Flight Performance Reserve and PPR		1,710	1,710
Thrust Decay		100	100
Power Roll Propellant		39	-
MS-IVB-1 Residuals		1,823	1,823
Pressurization Gas (Fuel)	369		
Pressurization Gas (Oxidizer)	436		
Fuel - Trapped	501		
Oxidizer - Trapped	459		
Auxiliary Propellant Reserve	15		
Environmental Control Fluids	43		
		317,461	88,889

* Includes ullage rocket cases (243 lb)

TABLE X. FIRST STAGE WEIGHT SUMMARY: S-IB WITH 120-INCH SOLID STRAP-ON AND UPRATED S-IVB (MLV-SAT-IB-8-SO) [Ref. 6]

(8 x 200K lb thrust, I_{sp} = 258.8 sec, SL)
(2 x 1,000K lb thrust, I_{sp} = 224 sec, SL)

		LIFT-OFF WEIGHT (LB)	SEPARATION WEIGHT (LB)
Second Stage Lift-off		463,613	463,613
MS-IB-3(SO)/MS-IVB-2 Interstage		8,015	8,015
MS-IB-3(SO)/MS-IVB-2 Sep/Start Loss		750	750
MS-IB-3(SO) Stage (Dry)		98,200	98,200
Mainstage Propellant (LOX/RP-1)		882,431	-
Residuals		11,050	11,050
Pressurization Gas (Fuel)	44		
Helium Trapped	36		
Fuel Bias	1,900		
Pressurization Gas (Oxidizer)	3,279		
Nitrogen Trapped	14		
Hydraulic Oil	28		
Fuel Trapped	2,957		
Oxidizer Trapped	2,792		
Thrust Decay		4,301*	241
Liquid Service Items		1,579	-
Solid Motor Propellant		824,000	-
Solid Motor Liners, Nozzles, Chambers, etc		106,040	106,040
		2,399,979	687,909

$(T/W)_{LO} = 1.496$

*Includes 2,177 lb for inboard engines thrust decay and 1,883 lb for outboard engines thrust decay to .8 sec outboard engine cutoff

TABLE XI. SECOND STAGE WEIGHT SUMMARY: S-IB WITH 120-INCH SOLID STRAP-ON AND UPRATED S-IVB (MLV-SAT-IB-8-SO) [Ref. 6]

(1 x 315K lb thrust, I_{sp} = 444.6 sec, vac)

		LIFT-OFF WEIGHT (LB)	CUTOFF WEIGHT (LB)
Gross Payload		71, 543	71, 543
Instrument Unit		4, 059	4, 059
MS-IVB-2 Stage (Dry)		35, 043*	34, 800
Mainstage Propellant (LOX/LH_2)		347, 810	-
Flight Performance Reserve and PPR		2, 190	2, 190
Power Roll Propellant		39	-
Thrust Decay		130	130
MS-IVB-2 Residuals		2, 799	2, 799
Pressurization Gas (Fuel)	555		
Pressurization Gas (Oxidizer)	663		
Fuel - Trapped	793		
Oxidizer - Trapped	730		
Auxiliary Propellant Reserve	15		
Environmental Control Fluids	43		
TOTAL		463, 613	115, 521

*Includes ullage rocket cases (243 lb)

The burning time for the 305-cm diameter motor is approximately 120 seconds as compared to approximately 148 seconds for the S-IB stage. The boost-assist motors will probably be separated from the vehicle prior to S-IB stage burn-out. The method is being used on the THORAD and, therefore, is considered as present state of the art.

The launch weight to payload weight ratio is about 43.2, as compared to 39.8 for the basic Saturn IB vehicle.

Additional loads on the S-IB stage and S-IVB stage resulting from the use of boost-assist solid motors and the additional payload weights have not been investigated sufficiently to determine structural weight increase. However, it is estimated that the increase in weight will be of the same order as the 396-cm boost-assist motor.

Also, operational and total cost effectiveness have not been estimated, but it is felt the cost will be slightly higher than that for the 396-cm boost-assist configuration.

SECTION IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The significant conclusion, based on the results of preliminary calculations and the very basic configuration considered, is that large solid rocket motors can be used efficiently to increase the orbital payload capabilities of the Saturn IB launch vehicle if required. Payload increase in the order of 170 percent may be realized with the proper combination of the Saturn IB vehicle and solid motors.

Use of solid motors as boost-assist or as a booster stage will give the launch vehicle greater flexibility over a large range of payloads without severe penalties to the basic vehicle structure or launch facilities, once the required basic modifications are made. For example, the payload capability may be varied on the boost-assist vehicle by varying the number of segments in the solid motors, or on the solid boosted vehicle by varying the length or propellant loading of the solid booster motor. Of course, modifications to the basic vehicle to accommodate this flexibility must be made and will probably incur a weight penalty and may require a flight qualification test. This test may be in conjunction with a low priority payload mission. Once the system has been put into operation, this flexibility will probably result in very little fluctuation in payload to orbit cost.

B. RECOMMENDATIONS

The following areas are recommended for future consideration and investigation:

1. A more detailed investigation of the solid boost-assist Saturn IB using the 305-cm diameter solid motors. The investigation should include such factors as effects of loads, acoustics, vibration, base heating, etc., on the complete vehicle.

2. A more detailed investigation of the solid boosted Saturn IB using the 660-cm diameter solid motor. The investigation should include such factors as effects of acoustics, vibration, base heating, etc., on the complete vehicle.

3. A comparison of the investigations recommended in items 1 and 2 should be made, taking into consideration common basic ground rules as to payload capability, launch and test facilities requirements, logistics, cost, and time schedules.

4. An investigation into the penalties, problems, cost, etc., in a basic vehicle design having performance flexibility through varying the performance of the solid motors. This may be advantageous when employing a segmented solid motor.

5. An investigation to establish the increase in performance and cost advantage, if any, that may be realized through the optimization of the solid motors, i.e., diameter, propellant loading, length, pressure, etc., for the boost-assist and solid boosted Saturn IB class vehicles.

6. An investigation of probable missions that would use the Saturn IB and uprated Saturn IB to determine if it is desirable to extend the efforts beyond the present status.

Additional studies recommended under items 1, 2, and 3 have been initiated and are presently being conducted by Chrysler Corporation and Douglas Aircraft Company.

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September 10, 1964 APPROVAL TM X- 53083

ORBITAL PAYLOAD POTENTIAL: SATURN IB EARTH LAUNCH VEHICLE USING SOLID PROPELLANT MOTORS

By

M. A. Page

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This report has also been reviewed and approved for technical accuracy.

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